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Rural household energy consumption characteristics and determinants in China

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ABSTRACT

For a developing country with a large rural population, to understand the rural households' energy consumption characteristic and energy consumption determinants for further public policy design is of increasing importance. Therefore, this paper provides a detailed analysis of the characteristics of rural households' energy consumption. Simultaneously, based on the data of 1472 rural households from the Chinese General Social Survey of 2015, the energy consumption determinants of rural households are estimated by Tobit model. Results reveal that rural households with a healthy and old household head reduce the share of coal consumption, and household labors with an off-farm job and high level of education, and a large household size increase the share of LPG and electricity consumption. The good economic condition of rural households contributes to the reduction of biomass consumption. Given the results, the government should work for poverty reduction, subsidies for modern equipment purchase, policies of effective and renewable energy technologies, and educational investment in rural areas, which may help for a positive transition in energy consumption for rural households.

1. Introduction

The changes in economic development, the process of urbanization, living standards, and climate have made great contributions to the variation in household energy consumption [1]. Especially in developing countries, rural household energy consumption accounts for a significant proportion of total energy consumption of a country. Moreover, tradition fuels, including agricultural and animal waste, fuelwood, and coal play a dominant role in household energy consumption in the rural area of these countries. For example, 92% of households use biomass in the disregarded villages of Bangladesh [2]; fuelwood is the major energy form in Nepal, accounting for 76.20% of the total energy consumption [3]; biomass energy (natural organic fuels) constitutes a high proportion of total national energy use for rural African [4]. Excessive use of biomass energy lead to environment degeneration [5] and emitting of several air pollutants [6]. Moreover, the increasing use of coal also has a negative impact on the rural environment, because the coal combustion plays a vital role in the carbon dioxide, nitrogen oxide, sulfur dioxide, and total suspended particulates emissions [7]. Therefore, rural households face a series of considerable, interlocking challenges in the coming transition to a low-carbon energy system with the requirement of reducing emission as well as the use of clean and renewable energy [8].

Similar to most of the developing countries, biomass also accounts for a large share of total energy supply (61.4%) and is the type of fuel most commonly used in rural China [9]. As the largest developing country with about 577 million people living in rural areas at the end of 2017, accounting for 41.5% of the total Chinese population [10], understanding the ways of energy use of rural households in China will be of increasing importance [11]. Hence, an increasing number of studies have focused on energy consumption in rural China. Early studies mainly presented the characteristics of rural household energy consumption in China through descriptive statistics [12–14], then with the available data based on household level, an increasing number of scholars drew their attention to analyze factors affecting energy consumption in rural China based on various empirical approaches and datasets. For instance, evidence from three villages in Jiangxi province reflected

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the relationship between labor input into fuelwood collection and energy decision of rural households by a household model [15], and the relationship between off-farm employment and energy decision by a village-level CGE-model [16]. A case study of 533 rural households from Yunnan province estimated the impact of Collective Forest Tenure Reform in China on rural household energy consumption [17]. The influence of off-farm income on rural household energy expenditures was examined by the data of 493 rural households from rural Gansu, Henan and Shandong provinces [18]. Additionally, some literature explained the impact of socio-economic transition on the inequality of energy use in urban and rural residents in China [19], rural households energy transition [20], rural household energy sustainable development [21] according to the province-level panel data of China.

In our review of previous literature, we found that different rural household surveys have been conducted in various regions to address the theme of rural household energy consumption. However, various regions are characterized by the different climate, natural resources, the density of population, lifestyles and so on, which means that there are regional variances and the representativeness of survey data is limited. Moreover, some energy consumption data collected in an early period in previous studies [14,22,23] may fail to reflect the changes in the external environment and its effects on rural household energy consumption in recent years. This is because great achievements exists in the China's rural energy reform in the last decade such as the improvement of energy commercialization, overall update of the energy use infrastructures (7.7 billion Yuan of investments in 2012), 100% of the power-connection rate, and 100% of electricity access rate (by 2015) in rural areas [24]. Though some studies explored the characteristics of rural household energy consumption by using a large sample of 1440 households in 8 typical counties of 8 China's economic zones [25], or a sample of 6000 rural households in 30 rural counties in 25 provinces in China in 2010 [26], which increased the sampling representativeness and explanatory power in the research, they lacked of empirical analysis of rural households' choice and decision of energy consumption. Otherwise, apart from the choice of cooking fuel [27], main of the empirical literature focused on a particular energy source, such as straw [28], firewood [29], biogas [30,31], while few of them considered the rural households' decision of energy consumption.

Therefore, this paper attempts to describe the characteristics of rural household energy consumption in detail and examine the factors affecting their energy consumption in rural China. It is worth noting that there are many choices to be made for rural household daily energy use, such as cooking, lighting, and appliances. There are numerous factors that influence their choices, including socio-economic and cultural factors [27], household characteristic [32], price and reliability in the supply of fuels [33], dwelling attributes [34], etc. Hence, following the previous literature, this paper provides an empirical analysis of household energy consumption by taking household socio-economic characteristics and dwelling characteristics into account.

This paper distinguished from previous studies in various ways. First, we use a new comprehensive survey data on rural household energy consumption covering 478 villages in 22 provinces, 4 autonomous regions, and 4 municipalities of China, which can help to well reflect the characteristics of current energy use by rural households in China. Second, we display the detailed and more comprehensive characteristics of rural household energy consumption with this dataset. Third, other than previous studies which only analyzed rural households' energy choices,.this paper uses the Tobit model to examine the factors affecting the share of a rural household's consumption of five main sources of energy to total energy consumption (including coal, liquefied petroleum gas, natural gas, biomass, and electricity). If the household did not use an energy source, the measure of this energy use was censored at zero. In this case, the common least squares regression will generate inconsistent parameter estimates, while the Tobit model is appreciated for the censored data and can consistently estimate the model parameters [35]. Since rural households usually use a variety of energy sources to meet their life energy requirement and rarely dependent on a particular fuel, the explanation of rural household energy consumption intensity is more important from a policy standpoint.

The rest of this paper is organized as follows. Section 2 introduces the data and general feature of rural household energy consumption in China. In section 3, we briefly describe the methodology. Section 4 presents the results and discussion. Section 5 concludes with a summary and suggestions.

2. Data and characteristics of rural household energy consumption

2.1. Data

Data from the Chinese General Social Survey (CGSS) of 2015 conducted by Science and Technology of Renmin University and Hong Kong University, which covered 478 villages in 22 provinces, 4 autonomous regions, and 4 municipalities of China.[1] About 10,968 rural households were selected through the procedure of the multi-step stratified random sampling, and detailed information about socioeconomic situations, demographic characteristics and so on for rural households were provided, suggesting that the sample for the survey is highly representative. Among these households, only one-third of the respondents were randomly selected to answer the questions of energy consumption. After accounting for missing observations and rural areas, we finally obtained 1472 valid observations for analysis. Currently, it is the most comprehensive and up-to-date national residential energy utilization database in China.

The characteristics of the sampled rural households are presented in Table 1. It should be noted that the data used in this study were collected from respondents who were most familiar with the family situation so that most of the respondents were the head of a household. It can be observed from Table 1 that approximately 48% of the sampled household head were male, and about 56% of them had primary school education or below education. It suggests that our samples were relatively less educated. About 21% of the household heads were engaging in an off-farm job. A large part of the sampled households had a small scale of family members, such as 668 households with the size of 1–2 persons, 576 households with the size of 3–4 persons, accounting for 45.38%, 39.13% of the sample respectively. 491 sampled rural households reported that their household income was less than 15000 CNY, accounting for one-third of the sample. Besides, about 30% of the rural household income was between 15000 CNY to 30000 CNY.

2.2. Characteristics of rural household energy consumption

Fig. 1 presents the rural households' choice of energy sources. CGSS focus on the relatively common use energy sources in rural China, which comprised of electricity, fuelwood, liquefied petroleum gas (LPG), coal, straw, gasoline, natural gas, diesel, livestock manure, and coal gas. Note that most of the Chinese households have access to electricity since the end of 2015, the most prevalent

[1] Data source: Chinses General Social Survey, http://www.chinagss.org/index.php?r=index/artabout&aid=16.

Table 1
Description of the sample (N = 1472).

Variable		Observation	Percent	Variable		Observation	Percent
Household head:				Household income (thousand CNY)	<15	491	33.36
Gender	male	708	48.10		[15,30]	445	30.23
	female	764	51.90		(30,50]	242	16.44
Education	primary school and below	819	55.64		(50,80]	161	10.94
	junior high school	444	30.16		>80	133	9.04
	senior high school	152	10.33	household size (person)	[1,2]	668	45.38
	above senior high school	57	3.87		[3,4]	576	39.13
off-farm job	yes	307	20.86		[5,6]	197	13.39
	no	1165	79.14		>6	31	2.11

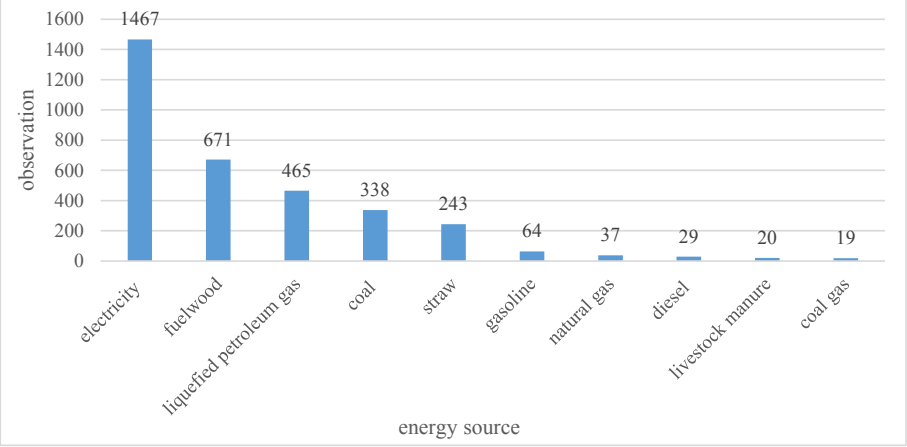

Fig. 1. The number of users for each energy source.

energy source is electricity. The number of rural households who used fuelwood is 671, indicating that fuelwood still plays a vital role in the rural household's energy consumption. About one thired (465) of the sampled households used the liquefied petroleum gas, followed by rural households who used coal (338), accounting for about 23% of the sample. The number of rural households who consumed straw is 243. The remaining sources of energy are less prevalent as the number of rural households used each of them is less than 70.

Table 2 displays the total amount of each energy consumption of all the sampled rural households. The first column shows the sampled rural households' physical consumption amount of ten types of energy sources. In order to compare the total consumption for each energy source, we convert the amount of each energy source consumption into kilograms of standard coal. As we can see that the most energy that sampled rural households consumed is fuelwood (about 1.9 million kgce), accounting for 55.22% of the total amount of energy consumption. The second is electricity because its consumption amount is about 583 thousand kgce and the proportion is about 17%. Next is the straw, accounting for 12.5%. Rural households also consumed much coal as its consumption amount is 357171.43 kgce, accounting for about 11%. Other less prevalent energy sources include LPG (2.03%), gasoline (1.23%), diesel (0.48%), natural gas (0.37%), livestock manure (0.09%) and coal gas (0.06%).

In order to further analyze the characteristics of rural household energy consumption, this paper mainly focuses on five categories of energy sources that are commonly used. Since straw and fuelwood are both traditional biomass energy, they are classified into one group named biomass. Similarly, we classify the natural gas and coal gas into one group named gas. In all, we pay attention to these five categories of energy, including coal, LPG, gas (natural gas and coal gas), biomass (straw and fuelwood) and electricity.

Table 3 shows the per capita energy consumption for these five categories of energy sources, according to per capita household income quartile, dwelling area quartile and the category of

Table 2
Description of sampled rural household energy consumption amount.

Energy source	Physical amount of consumption	Coefficient of standard coal	Total consumption (kgce)	Percent of consumption
Coal	500030.00 kg	0.7143	357171.43	10.65
Gasoline	28132.29 kg	1.4714	41393.85	1.23
Diesel	11091.42 kg	1.4571	16161.31	0.48
LPG	39719.10 kg	1.7143	68090.45	2.03
Natural gas	10090.00m^3	1.2143	12252.29	0.37
Coal gas	3718.50m^3	0.5777	2148.18	0.06
Livestock manure	34690.00 kg	0.0876	3038.84	0.09
Straw	838180.00 kg	0.5000	419090.00	12.50
Fuelwood	3242993.00 kg	0.5710	1851749.00	55.22
Electricity	1820424.00Kwh	0.3200	582535.68	17.37

Table 3
Per capita energy consumption (kgce).

Variable	Category	Coal	LPG	Gas	Biomass	Electricity
Per capita household income (CNY)	quartile1 (0–3500)	175.38	26.24	10.02	1627.68	311.94
	quartile2(3570–8334)	243.64	47.76	5.46	1577.60	407.93
	quartile3(8500–16250)	287.56	50.16	5.32	1819.19	428.25
	quartile4(over 16300)	264.83	60.92	18.33	1150.89	435.25
Household size (person)	1 and 2 (45.38%)	131.60	18.89	3.61	1058.29	197.29
	3 and 4 (39.13%)	73.28	15.57	4.72	480.65	124.53
	above 4 (15.49%)	44.47	12.63	0.96	206.17	96.74
Dwelling area (square meter)	quartile1 (10–80)	110.89	16.36	1.38	1059.38	149.88
	quartile2 (81–120)	102.01	14.00	3.56	791.72	148.48
	quartile3 (121–200)	74.55	16.77	4.82	550.55	158.14
	quartile4 (over 200)	94.75	21.64	5.18	240.74	158.77

household size. It can be observed that the per capita consumption of LPG and electricity for rural households increases with the level of per capita household income, while the rural households with the lowest per capita income (quartile1) consume more biomass than other rural households. Additionally, rural households with medium per capita income (quartile2 and 3) consume more coal and less gas than rural households with the lowest income quartile. It has been observed that the per capita consumption of LPG and electricity rise with the increase of per capita household income. This result is in line with the study of Miah, Kabir [2] who claimed that rural household's energy consumption was highly affected by income and the increase in household income led to the change of traditional energy use into more efficient energy use. Given the household size, there is an obvious relationship that the smaller the household size, the higher the energy consumption per capita in rural households. Although Tso and Guan [36]indicated that each extra person living in a house contributed to the expected increase of household energy consumption by 219,811 kWh/year, but the per capita energy consumption would reduce by household size because lighting, heating and other services are shared by more people in larger households. The area of a dwelling may have impacts on energy consumption by the space of illumination and heating. With the increase of dwelling area, the per capita consumption of gas and electricity also increase. However, rural households in the smallest dwelling (quartile1) have the highest per capita consumption of coal and biomass. Moreover, rural households in the largest dwelling (quartile4) have the highest per capita consumption of LPG.

To our knowledge, the determination of energy sources and consumption for rural households is influenced by the geographical factors [37], therefore we provide the main five categories of energy consumption for rural households by various regions of China. According to the geographical features, the whole country of China is divided into seven geographical zones, including Central east zone, Central north zone, Central zone, South zone, Southwest zone, Northwest zone, and Northeast zone [38]. There are differences in climate, economic development, population density, natural resources, institutions and policies among the seven zones.

Fig. 2 displays a brief overview of the sampled rural households' energy consumption structure of each zone of China based on the distribution of sampled rural households. Among the five major energy categories, the proportion of biomass consumption is over 50% of the total of five major energy sources consumption in the six zones, except for central north. This reveals that the biomass is still an important part of the rural household's energy consumption. Especially for rural households in the northeast and south of China, the proportion of biomass consumption reaches 80%. Perhaps these two zones are both rich in forest resources so that rural households can depend on the biomass. Similar to the rural households in the south of China, the consumption of biomass for rural households in southwest and central accounts for 76%, 70%, respectively. One possible explanation is that per capita household income of the rural household in the two zones is low and these zones are rich in the forest so that rural households are more willing to consume the available and free biomass. Rural households in central north zone mainly rely on coal (47%) and electricity (28%). The strong

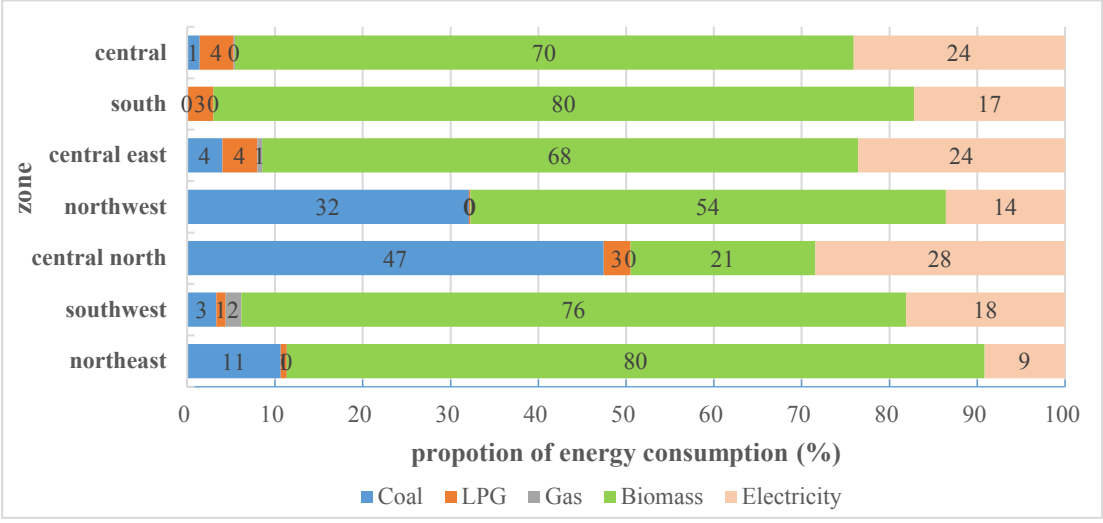

Fig. 2. Rural household energy consumption structure of each zone of China.

dependence on coal may be because Shanxi province and central Inner Mongolia which belong to the central north zone are rich in coal resource. Rural households in the northwest zone also consumed a large proportion of coal (32%) and biomass (54%). Compared to other energy sources, the proportion of the consumption of LPG and gas is relatively small for rural households. For instance, the LPG consumption for rural households in the central and central east of China accounts for both 4%, while the gas consumption only accounts for 2%, 1% of rural households in the southwest and central east of China, respectively.

Table 4 provides the per household energy consumption of each zone of China. Per household energy consumption for sampled rural households in the northeast of China (about 4168 kgce) is much higher than that of other zones. For each energy source, the consumption of coal per household is much larger for sample households in the central north (758.86 kgce) and northwest (767.27 kgce). The consumption of LPG per household is much larger for sample households in the central east (76.79 kgce) and south (64.65 kgce). Compared to other rural households, the consumption of gas per household for sampled households in the southwest (36.39 kgce) is much larger than the average level of gas consumption per household (7.30 kgce). Except for the central north zone (336.33 kgce), the biomass consumption per household for the rest zones is close to the average level of consumption (1513.81kgce). The electricity consumption per household in the central north (455.10kgce) and central east (455.85kgce) is much larger than the average level of electricity consumption per household (389.28 kgce).

3. Methodology

One of the purposes of this study is to analyze the determinants of rural household energy consumption in China. Though rural households consume various energy sources simultaneously, this study mainly focuses on five categories of energy sources which account for over 90% of rural households' total energy consumption. Therefore, this study considers the share of the amount of each type of energy for a rural household and set the share to five dependent variables, including the share of the consumption amount of coal (S_{co}), LPG (S_{LPG}), gas (S_{gas}), biomass (S_{bio}), and electricity (S_e). Thus, a rural household' energy consumption structure (S_{econ}) in this study can be expressed as:

$$S_{econ} = f(S_{co}, S_{LPG}, S_{gas}, S_{bio}, S_e) \tag{1}$$

We can assume a rural household (i) with the household characteristic H, lived in the dwelling with characteristic D in one zone of China (Z). The decision of energy consumption for rural household (i) is affected by the head of the household who is the main decision maker, other household characteristics, dwelling with characteristic and other external factors [39]. Considering all these constraint conditions, the determination of a rural household' energy consumption can be expressed as a utility maximization problem with respect to the household characteristic, dwelling characteristic and other external factors (θ). That is:

$$\text{Maximize} \mathrm{U} = \mathrm{U}(I, E; H, D, Z, \theta) \tag{2}$$

Subject to the constraints:

$$C + E = I \tag{3}$$

$$\mathrm{E} = \mathrm{Q}S_{econ} * P = \mathrm{Q}P_{co}S_{co} + \mathrm{Q}P_{LPG}S_{LPG} + \mathrm{Q}P_{gas}S_{gas} + \mathrm{Q}P_{bio}S_{bio} + \mathrm{Q}P_eS_e \tag{4}$$

where C is the total expenditure for other good consumption except for energy, and E is the expenditure on energy consumption. I is the total income of a rural household. Note that the total amount of energy consumption is Q, the expenditure for energy consumption equals the amount of each energy source multiplies by its corresponding price. Equivalently, the optimality conditions can be obtained by a Lagrange function :

$$\mathrm{U} = \mathrm{U}(I, E; H, D, Z, \theta) + \lambda\left[I - C - \left(\mathrm{Q}P_{co}S_{co} + \mathrm{Q}P_{LPG}S_{LPG} + \mathrm{Q}P_{gas}S_{gas} + \mathrm{Q}P_{bio}S_{bio} + \mathrm{Q}P_eS_e\right)\right] \tag{5}$$

Solving Equation (5) for the first-order optimality conditions can obtain the estimable form of rural household's decision of energy consumption model. Following the study of Zhang and Koji [7], the basic model for the five energy sources consumption share functions can be specified as follows:

$$\begin{bmatrix} S_{co} \\ S_{LPG} \\ S_{gsa} \\ S_{bio} \\ S_e \end{bmatrix} = f(I^*, H, D, Z, \theta) \tag{6}$$

where I^* denotes the per capita household income per year. H refers to the characteristic of the rural household, including the age, gender, physical health, education and occupation of household head, the education and occupation of his (her) spouse. Moreover, the household size, number of minors and per capita expenditure per year (consumer goods, leisure entertainment, communication, etc.) are taken into account. The dwelling with characteristic D covers the dwelling area, the year of construction of the dwelling. Consider the external and unobservable factors (θ), such as the heterogeneity of resource, economic development, institutional control and culture settings among these regions, we controlled zones (Z) in the function. Since sampled rural households can be grouped into village-level clusters according to the sampling method, the within-cluster error correlation may lead to very misleadingly small standard errors, narrow confidence, and lower p-values [40], the Tobit model for within-cluster error correlation is correctly specified.

As the value of the share of five categories of energy consumption is range from 0 to 1, the Tobit regression method is appreciated to address the problem of zero values for each energy's share in the model [7]. Therefore, we apply the Tobit regression method to estimate the factors affecting rural household's energy consumption in this study. Moreover, in order to further analyze the degree of influence of the factors affecting the rural household's energy consumption, we calculate the marginal effect of estimated parameters when considering only the rural household consume this type of energy source. According to Cameron and Trivedi [41], the marginal effect can be explained as follows:

Table 4
Per household energy consumption in seven zones of China (kgce).

Zone	Coal	LPG	Gas	Biomass	Electricity	Total
Northeast	444.81	27.72	0.53	3313.69	381.28	4168.03
Southwest	67.01	21.42	36.39	1528.27	365.13	2018.22
Central north	758.86	49.04	0.00	336.33	455.10	1599.33
Northwest	767.27	3.59	0.78	1295.00	324.67	2391.31
Central east	77.46	76.79	10.86	1312.67	455.85	1933.63
South	0.00	64.65	0.00	1717.10	369.22	2150.98
Central	21.92	59.99	2.57	1093.64	373.78	1551.90
Average	305.33	43.32	7.30	1513.81	389.29	2259.06

$$\partial E(S_j|X, S_j > 0) / \partial X = \left[1 - \omega\lambda(\omega) - \lambda(\omega)^2\right]\beta \quad (7)$$

Table 5 presents descriptive statistics for factors identified in this study that might influence the share of five categories of energy consumption for rural households. The top portion of Table 5 displays the five dependent variables. On average, the share of electricity consumption is high (0.417), followed by the share of biomass consumption (0.391). The second proportion of Table 5 shows the statistic of various socioeconomic-demographic characteristics of the rural household. The sampled rural households' average age is about 52, with about 21% engaged in an off-farm job. The mean of rural households' education is 1.624 and the mean of spouse's education is 1.972, suggesting that the education level of many rural households is relatively low. The average household size for the sampled households is about 3 persons, and the mean of the number of minors in a household is about 0.4. This reveals that the size of sampled rural households is small. The per capita annual income for the household is about 16,256 CNY, while the per capita annual expenditure (including consumer goods, leisure entertainment, communication, etc.) is just approximately 385 CNY, accounting for 2.4% of the per capita annual income, approximately. The average area of rural household's dwelling is about 146 m^2. The mean of the dwelling year is approximately 3, suggesting that a large number of the dwellings were built around the 1990s. Based on the landform of sampled provinces, provinces can be divided into three groups such as plain region, hill region and mountainous region. Table 5 displays that over half of these provinces belong to the mountainous region, following by the plain region (24.1%) and the hill region (19.4%).

4. Results and discussion

Table 6 reports the Tobit regression results for the share of five energy sources consumption. We extend these results to marginal effects (MEs) and robust standard errors. Table 7 presents the results of the variance inflation factors (VIFs) for the independent variables in the Tobit model. The mean VIF equals to 2.19 and the VIFs of all the independent variables used in the Tobit model are below 7, suggesting that the correlation among these variables is weak, and thereby there is not a multicollinearity problem in the data.

The top of Table 6 presents the impacts of the head of household's characteristics on rural household energy consumption. Results suggest that the gender of a head household has no significant impact on rural household energy consumption. The age of the household head has a significant and negative effect on the share of coal consumption, but has a positive effect on the share of gas consumption, implying that an additional increase of age (measured by year) reduces the share of coal consumption by 1.7%, and raises the share of gas consumption by 3.7%. This finding is in line with the research of Mensah and Adu [33]. A possible explanation is that with the increasing of age, rural households accumulate more knowledge about different energy sources and their awareness of environmental protection also enhance, which leads to and prefer to use gas which is clean and easy to use but reduce the use of coal. The household head's health level has a significant influence on these five energy sources, suggesting that the level of the household head's physical health plays an important role in the energy consumption structure of rural households. The coefficients on the variable *Health* indicate that the health of the household head has a significant and positive impact on the share of LPG and electricity consumption, while has a significant and negative impact on the share of coal, gas and biomass consumption. Findings display that the improvement of the health level of household head increases the share of LPG and electricity consumption by 0.6% and 0.9%, but reduces the share of coal, gas and biomass consumption by 0.4%, 0.5%, 1.1%, respectively. It is possible that good health can enhance household head's working capability and thereby increase their income [42], and household with higher income may switch to using LPG and electricity from biomass and coal according to the energy ladder model of household fuel choice [43].

Table 6 shows that there is a significant positive correlation between household head's education and share of LPG, electricity consumption, while there is a significant negative relationship between education and share of biomass consumption. The

Table 5
Definition and summary statistics of the variables (N = 1472).

Variable	Definitions	Mean	Std.Dev
S_{co}	share of the amount of coal consumption to total five categories of energy consumption for a year	0.120	0.250
S_{LPG}	share of the amount of LPG consumption to total five categories of energy consumption for a year	0.059	0.116
S_{gas}	share of the amount of gas consumption to total five categories of energy consumption for a year	0.013	0.077
S_{bio}	share of the amount of biomass consumption to total five categories of energy consumption for a year	0.391	0.392
S_e	share of the amount of electricity consumption to total five categories of energy consumption for a year	0.417	0.323
Independent variable			
Gender	= 1 if the household head (HH) is male, 0 otherwise	0.481	0.500
Age	age of household head (year)	52.384	15.729
Health	level of physical health of HH: 1 = very unhealthy, 2 = relatively unhealthy, 3 = medium, 4 = relatively healthy, 5 = very healthy	3.465	1.143
Education	the HH's education: 1 = primary school and below education (base group), 2 = junior high school education, 3 = senior high school education, 4 = above senior high school education	1.624	0.821
Off-farm job	= 1 if HH engaged in an off-farm job, 0 otherwise	0.209	0.406
Spouse's education	spouse's education: 1 = primary school and below education (base group), 2 = junior high school education, 3 = senior high school education, 4 = above senior high school education	1.972	1.143
Spouse's job	= 1 if his (her) spouse engaged in an off-farm job, 0 otherwise	0.224	0.417
Household size	the resident population of respondent's family (person)	3.007	1.465
Minor	the number of minors of respondent's family (person)	0.418	0.770
Income	per capita annual income for the household (CNY)	16256.240	105918.500
Expenditure	per capita annual expenditure for the consumer goods, leisure entertainment, communication, etc. (CNY)	384.526	596.226
Dwelling area	the area of household's dwelling (m^2)	146.371	102.390
Dwelling year	the year of construction of the dwelling: 1 = before 1970(base group), 2 = 1970–1989, 3 = 1990–2009, 4 = after 2009	2.714	0.863
Plain region	= 1 if the province where the household lived belong to plain region, 0 otherwise	0.241	0.428
Hill region	= 1 if the province where the household lived belong to plain region, 0 otherwise	0.194	0.396
Mountainous region	= 1 if the province where the household lived belong to plain region, 0 otherwise	0.565	0.496
zone	dummy variables for seven zones of China		

Table 6
Results of Tobit model regression for the share of energy consumption.

Variables	Coal		LPG		Gas		Biomass		Electricity	
	Coefficient	MEs	Coefficient	MEs	Coefficient	MEs	Coefficient	MEs	coefficient	MEs
Gender	−0.031	−0.006**	−0.023	−0.006	0.075	0.006	0.032	0.015	−0.014	−0.011
	(0.023)	(0.003)	(0.017)	(0.004)	(0.048)	(0.007)	(0.034)	(0.015)	(0.017)	(0.013)
Age (ln)	−0.088***	−0.017***	0.058	0.015*	0.467***	0.037*	−0.085	−0.039	0.046	0.034
	(0.008)	(0.004)	(0.035)	(0.009)	(0.016)	(0.021)	(0.068)	(0.031)	(0.035)	(0.026)
Health	−0.019**	−0.004***	0.024***	0.006***	−0.059***	−0.005***	−0.024*	−0.011*	0.012*	0.009*
	(0.008)	(0.000)	(0.008)	(0.002)	(0.016)	(0.001)	(0.014)	(0.007)	(0.007)	(0.005)
Education	0.005	0.001	0.025**	0.006**	0.120***	0.010	−0.067***	−0.031***	0.029**	0.022**
	(0.014)	(0.003)	(0.012)	(0.003)	(0.026)	(0.007)	(0.024)	(0.011)	(0.011)	(0.009)
Off-farm job	−0.056***	−0.011***	0.079***	0.020***	0.321***	0.026	−0.294***	−0.134***	0.123***	0.092***
	(0.020)	(0.001)	(0.023)	(0.006)	(0.045)	(0.017)	(0.054)	(0.024)	(0.025)	(0.019)
Spouse's education	0.008	0.002	0.002	0.001	0.090***	0.007	−0.030**	−0.014**	0.012	0.009
	(0.010)	(0.002)	(0.008)	(0.002)	(0.019)	(0.005)	(0.014)	(0.007)	(0.008)	(0.006)
Spouse's job	−0.058***	−0.011***	0.049**	0.012**	−0.034	−0.003	−0.144***	−0.066***	0.061***	0.046***
	(0.019)	(0.001)	(0.019)	(0.005)	(0.043)	(0.002)	(0.044)	(0.020)	(0.023)	(0.017)
Household size	0.018**	0.003	0.015**	0.004**	0.027*	0.002	−0.026*	−0.012*	0.011*	0.008*
	(0.007)	(0.003)	(0.006)	(0.002)	(0.015)	(0.002)	(0.014)	(0.006)	(0.006)	(0.005)
Minor	−0.015	−0.003**	0.015	0.004	−0.002	−0.000	0.019	0.009	−0.014	−0.011
	(0.011)	(0.001)	(0.011)	(0.003)	(0.026)	(0.002)	(0.023)	(0.011)	(0.012)	(0.009)
Income(ln)	−0.009***	−0.002***	0.010*	0.003*	0.055***	0.004	−0.003	−0.002	−0.000	−0.000
	(0.003)	(0.000)	(0.005)	(0.001)	(0.007)	(0.003)	(0.008)	(0.004)	(0.005)	(0.003)
Expenditure(ln)	−0.010**	−0.002***	0.019***	0.005***	0.019*	0.001	−0.026**	−0.012**	0.014***	0.011***
	(0.005)	(0.000)	(0.006)	(0.002)	(0.011)	(0.002)	(0.011)	(0.005)	(0.005)	(0.004)
Dwelling area(ln)	0.118***	0.022***	−0.002	−0.001	0.092***	0.007	−0.131***	−0.060***	0.029*	0.022*
	(0.006)	(0.008)	(0.016)	(0.004)	(0.013)	(0.005)	(0.032)	(0.015)	(0.015)	(0.011)
Dwelling year	0.011	0.002	0.016	0.004	−0.094***	−0.007***	−0.037*	−0.017*	0.028**	0.021**
	(0.010)	(0.003)	(0.011)	(0.003)	(0.021)	(0.002)	(0.020)	(0.009)	(0.011)	(0.008)
Plain region	0.330***	0.063**	0.074*	0.019*	−0.090**	−0.007***	−0.143**	−0.065**	−0.004	−0.003
	(0.027)	(0.025)	(0.039)	(0.010)	(0.043)	(0.002)	(0.070)	(0.032)	(0.032)	(0.024)
Hill region	−0.080***	−0.015***	0.050**	0.013**	−0.285***	−0.023**	0.094**	0.043**	−0.032*	−0.024*
	(0.012)	(0.003)	(0.025)	(0.006)	(0.020)	(0.010)	(0.042)	(0.019)	(0.018)	(0.013)
Constant	−3.815***		−0.677***		−7.155***		2.079***		−0.264	
	(0.031)		(0.194)		(0.063)		(0.359)		(0.182)	
Sigma	0.597***		0.237***		0.626***		0.533***		0.293***	
	(0.013)		(0.011)		(0.026)		(0.019)		(0.006)	
Zones	YES		YES		YES		YES		YES	
Number of observations	1472		1472		1472		1472		1472	
Pseudo R^2	0.254		0.318		0.264		0.150		0.342	

Notes: Statistically significant at: *10, * *5 and * * *1% levels; robust standard errors clustered on village level are report in the parentheses. Marginal effect (dy/dx) for factor levels is the discrete change from the base level.

Table 7
Results of variance inflation factors (VIFs) for the independent variables.

Variable	VIF	1/VIF	Variable	VIF	1/VIF
Gender	1.17	0.85	Dwelling area(ln)	1.27	0.78
Age (ln)	2.09	0.48	Dwelling year	1.15	0.87
Health	1.25	0.80	Region_central	6.46	0.15
Education	1.61	0.62	Region_centraleast	4.56	0.22
Off-farm job	1.30	0.77	Region_southwest	4.22	0.24
Spouse's education	1.22	0.82	Region_northeast	4.19	0.24
Spouse's job	1.27	0.79	Region_northwest	3.03	0.33
Household size	1.25	0.80	Region_centralnorth	2.72	0.37
Minor	1.34	0.75	Plain region	1.60	0.62
Income(ln)	1.21	0.83	Hill region	1.88	0.53
Expenditure (ln)	1.23	0.81	Mean VIF	2.19	

corresponding marginal effects suggest that compared to a household head with primary school education or below, the rural household with a better-educated household head reduces the share of biomass consumption by 3.1%, but increases the share of LPG and electricity consumption by 0.6%, 3.1%, respectively. Similarly, the spouse's education also has a significant and negative influence on biomass consumption. Generally, higher education level means an individual is equipped with more relevant energy conservation and energy efficiency knowledge and environmental consciousness so that education has a vital influence on instilling energy efficient behavior [44]. Rural households with higher levels of education are more willing to choose clean energy sources [45].

There is a strong correlation between the off-farm employment and household energy consumption. Household head and his (her) spouse's participation in off-farm employment significantly affect rural household energy consumption. The marginal effects of variables *Off-farm job* and *Spouse's job* reveal that the household head and his (her) spouse's participation in off-farm job reduces the share of coal consumption by both 1.1%, and makes a decline in the share of biomass consumption by about 13% and 6.6%, but increases the share of consumption of LPG and electricity. A possible reason is that off-farm employment reduces the amount of labor available for biomass collection [16], and the LPG and electricity are more convenient to use and more effective.

The household size has a positive effect on the share of LPG and electricity consumption, suggesting that an additional increase in the household size (measured by person) increases the share of LPG and electricity consumption by 0.4% and 0.8% respectively. This finding refutes the study of Mensah and Adu [33], who stated that larger families are more likely to adopt fuelwood than modern fuels. Perhaps modern rural households tend to lead to a higher standard of life, including fuels that produce heat efficiently and rapidly. Per capita income and per capita expenditure can both assess the wealth of rural households. It can be observed from Table 6 that the variable income has a significant and negative impact on the share of coal consumption but has a significant and positive effect on the share of LPG and gas consumption. Furthermore, except for the similar results as the variable income, the variable expenditure has a negative influence on the share of biomass consumption but a positive impact on the share of electricity consumption.

Overall, these results suggest that rural households of a rich group reduce the coal and biomass consumption, but increase the consumption of modern fuels and commercial energy sources, which is in accordance with previous studies, such as Wang and Feng [14], Démurger and Fournier [29]. These authors claimed that income played a vital role in rural household's energy consumption and the fuelwood consumption declines with increasing income and with the increasing opportunity cost of fuelwood collection.

In addition, the dwelling characteristic also has a significant relationship with energy consumption. Findings show that an additional increase in the area of dwelling raises the share of coal and electricity consumption both by 2.2%, respectively, but decreases the share of biomass consumption by 6%. Previous research reported that the dwelling area also indirectly was correlated with household income and had a positive influence on household energy consumption [46]. Therefore, rural households lived in a larger dwelling may be richer and can afford commercial fuels. The marginal effects of the construction year of dwelling reflect that the rural households lived in the relatively new dwelling are more likely to depend on LPG and electricity, but rely less on gas and biomass. It is possible that modern buildings are equipped with modern equipment, which requires the use of modern energy sources other than traditional energy.

Finally, compared to rural households lived in the mountainous region, rural households lived in the plain region are more likely to consume coal, LPG, but are less likely to use gas and biomass. On the contrary, living in the hill region increases the likelihood of consuming biomass, but reduces the use of coal. Besides, rural households lived in the hill region tend to consume LPG instead of gas and electricity. A possible explanation is that there is better traffic conditions in the plain region than in the mountainous region, which is able to provide convention access to energy source and lower the transaction cost of coal and LPG. On the other hand, the hill region is rich in forest resources, which can make rural households easy to obtain biomass.

To further explain the impact mechanism of household characteristics on the choice of electric and LPG, we explored the impact of household characteristics on appliances quantity and cooking fuel by using the OLS model and profit model, respectively. That is because the using of domestic appliances and cooking fuel both play a vital role in rural household daily energy consumption. Results in Table 8 show that rural households with an off-farm job, higher education, and larger household size tend to use more household appliances, suggesting that they would choose to consume more electricity. Besides, rural households who lived in the dwelling with a larger area and relatively short construction year are also likely to have more household appliances.

Cooking fuel accounts for an important part of daily energy consumption in rural China. The results of the Probit model (=1 if household use LPG for cooking) display that rural households with a household head with higher education and an off-farm job increase the likelihood of using LPG for cooking. There is also a positive relationship between spouse's off-farm job and the probability of using LPG for cooking. Rural households with a large household size also tend to use LPG for cooking.

In brief, household characteristics especially the economic conditions may have impacts on rural household appliances using and cooking activities, which in turns influences rural household energy consumption.

5. Conclusions

This study provides the details of characteristics of rural household energy consumption by using a new comprehensive survey data of 1472 rural households collected by the Chinese General Social Survey (CGSS) on rural household energy consumption of China in 2015. Furthermore, we analyze factors affecting the share of rural household energy consumption (including coal, liquefied petroleum gas, natural gas, biomass, and electricity) in China. We find that the most prevalent energy source is electricity, following by fuelwood. The amount of fuelwood consumption accounts for 55.22% of the total amount of energy consumption. Moreover, rural households with low capita income, small household size, and the small dwelling area have a high level

Table 8
Impact of household characteristics on appliances quantity and cooking fuel.

Variables	M1(dependent variable: number of household appliances)		M2(dependent variable: if use LPG for cooking)	
	Coefficient	Robust standard error	Coefficient	Robust standard error
Gender	0.020	0.110	−0.043*	0.022
Age (ln)	0.267	0.196	0.133***	0.044
Health	0.136***	0.042	0.033***	0.010
Education	0.130*	0.069	0.058***	0.018
Off-farm job	0.471***	0.146	0.101***	0.032
Spouse's education	0.049	0.035	0.007	0.010
Spouse's job	0.568***	0.155	0.092***	0.031
Household size	0.309***	0.039	0.018**	0.008
Minor	−0.215***	0.057	0.007	0.016
Income(ln)	0.077***	0.020	0.011**	0.005
Expenditure(ln)	0.185***	0.023	0.015**	0.006
Dwelling area(ln)	0.520***	0.085	0.033*	0.019
Dwelling year	0.091*	0.047	−0.001	0.013
Constant	−4.170***	0.884	−0.920***	0.223
Number of observations	1472	1472		
R^2	0.227	0.080		

Notes: Statistically significant at: *10, * *5 and * * *1% levels.

of per capita consumption of biomass. Otherwise, rural household energy consumption proportion is different among the seven geographical zones of China.

The results of the Tobit model reveal significant relationships between the household characteristic, dwelling characteristic, and rural household energy consumption. Findings indicate that rural households with an old and healthy household head may reduce the share of coal consumption, while the high level of education, off-farm employment, large household size and construction year of dwelling are important factors for LPG and electricity consumption. The improvement of rural households' economic conditions such as off-farm employment, per capita income and expenditure, play a dominant role in the reduction of the share of biomass consumption. The landform of provinces also has significant effects on rural household energy consumption. Further exploration reveals that household characteristics have impacts on rural household appliances using and cooking activities, which in turns influences rural households' electric and LPG consumption.

Findings in this study have several policy implications. First, since the household economic condition is a key factor in the rural household's decision of energy consumption, it is of great importance for the government to reduce poverty, which may improve rural households' ability for a positive energy transition from traditional fuels to modern energy sources. For example, the government should adopt the policies to promote the transfer of the rural labor force in order to meet the need of urbanization of China and make them easy to access off-farm employment. As a result, the increase of rural household income should be possible. Second, our results present a positive relationship between dwellings' feature and modern energy consumption, which suggests that the improving the living conditions of rural households and subsidies for the purchase of modern equipment for rural households (including the heating, cooling, water-heating equipment and other kitchen equipment etc.) can promote the transition of rural household's energy consumption. Third, more attention are supposed to draw to the educational investment in rural areas because rural households with a higher education have a preference for modern and clean energy sources and may be more aware of environmental protection when they make decisions for the energy sources. Finally, the policymakers can also design the policies which help the rural households to adopt effective and renewable energy technologies and encourage them to use modern energy sources.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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